DESIGN, ANALYSIS AND PERFORMANCE EVALUATION OF A MECHANICAL GYRATOR

Abhilash P[1], Allen Varghese Abraham[2], Jibin Sam Jo[3],
Jobin Joseph[4], Arun K Varghese[5].
[1234]U. G. Student, [5]Assistant Professor.
[12345] Department Of Mechanical Engineering, Saintgits College of Engineering, Kottayam,Kerala.
E-Mail:[1]abhilash.p.nair0001@gmail.com, [2]allenabraham477@gmail.com, [3]jibinsamjo@gmail.com,
[4]jobin2020@gmail.com, [5]varghese_akv@yahoo.com.

Abstract-The project focuses on the development of an efficient and safe system for navigation for disabled people. Such a system should enable the user to control with minimum effort and should be stable in all practical situations. A gyrator is neither a motorcycle nor a four wheeler. It is a vehicle made up of an inner frame which is encompassed and supported by two large coaxially aligned wheels. The inner frame is supported by a common axle as a result, is free to oscillate back and forth relative to outer wheels. The inherent instability has limited its potential as a commercially available vehicle. But by reducing this oscillation to an optimum value by incorporating internal braking, we could make a very stable navigation system. In order to achieve motion, a shift in the centre of gravity of the inner frame is required. Two independent electric motors provide the driving torque to gearbox which drives the large outer wheels. This unique design gives the vehicle a clear advantage over conventional 4wheeled and 2wheeled vehicles as it has zero turning radius. Key word:- Inflation Pressure, Pressure switch ,Pressure guage, Solenoid control valve, DC Compressor.

Keyword:-Mechanical gyrator

I.INTRODUCTION

The Mechanical Gyrator's distinctive design makes it a novel alternative form of transport. One of the first recorded designs was by Mr Otto in 1870. The gyrator allows the driver to sit in a frame which is rigidly connected to the shaft surrounded by two large wheels. These two wheels cause the entire system to move when rotated. The independent control over each wheel allows the gyrator to rotate on the spot. The Gyrator is comprised of many typical subsystems. These subsystems must be integrated to provide an energy efficient system and all mechanical systems need to comply with relevant safety expectations. The main subsystems of the mechanical gyrator include two large outer wheels surrounded with tyre and tube, a drive system, brakes and a method for steering. The large outer wheels provide the motion of the gyrator. Since the wheels are quite large they require high torques to start moving. The materials used for the shaft should possess good wear resistive properties. The drive system provides the motion and is commonly powered by a motor which provides the torque required to move the Gyrator. Once in motion it must be stopped by a brake, which can be implemented electronically using the motors and mechanically using any common mechanical brake. One of the most important features requisite of a stable design is the internal braking. For controlling the yawing motion of the gyrator due to inertia, a good internal braking with suspension system should be provided between the outer wheels and inner frame. An energy efficient drive system is one that has minimal losses due to heat production and noise. Efficiency may be improved by using an electrical drive system. This system also has the potential to use regenerative braking to collect excess energy. This is when an electrical- motor is used as a generator and the back EMF is feedback into the battery. These motors need to be able to produce a significant amount of torque to be able to rotate the large wheels. In order to produce this torque the batteries need to be able to supply the motor with large currents. The incorporation of 120 degrees space positioning seat shifting mechanism and convertible seat-cum-bed increases the potential of the mechanical gyrator among people. The main objective of the project is to develop a user friendly and green vehicle with effortless driving. The project also focuses on convertible seat-cum-bed mechanism with 120 degrees space positioning seat shifting. The mechanical gyrator incorporating these facilities will serve as a good vehicle for physically challenged, partially blind and for aged. Another objective of the project is to fabricate a self-stabilizing vehicle with improved balancing techniques. This project continues its

scope for providing a method for using the seat even from the ground level.

The methodology is adopted confining to the primary objectives. Initially, the design of the vehicle has been made using hand sketches and CAD softwares like SolidWorks and CATIA. Our approach for this project was to bring out a successful vehicle with new innovations. Before beginning the design we must know the targets required for the gyrator. The figure 1 shows the final design of the mechanical gyrator

Fig. 1 Mechanical Gyrator

Main parts of the gyrator include:

1. Chassis
2. Wheels and tires
3. Transmission system
4. Seat
5. Shaft and Bearings
6. Electrical system

A. CHASSIS

Material Selection

Material selection was one of the most difficult part of the design process. There is a huge list of variety of different materials available for selection. Hence some major criteria's were shortlisted for the selection of materials. This includes:

Strength

Strength is one of the major influencing parameter in material selection as far as any project related to automobile is considered. For getting the required s trength the weight parameter may be compromis ed. Dens ity

The density of the material should be low as possible to reduce overall weight of the vehicle. The reduction in weight improves the transmission efficiency and improves the stability.

Cost

As the maximum budget for the project was very limited, from the very beginning, the taste of lack of finance was felt with both in terms of material cost and other expenditure and for the research and analysis.

The lack of finance demanded that the cost is put down to the lowest possible value so that the project is successfully completed with-in the stipulated time period.

Ease of Availability

As students requiring very less amount of materials for the work, it was difficult to find the materials in the market. Materials like carbon Fibre used for light weight vehicles were unavailable for the commercial access, which really restricted the material selection.

Ease of working

The lack of advanced facilities in college forced the project to select materials which can be worked with the machine shop facilities. DC and AC arc welding were available in the college so materials were chosen according to this.

The table 1 gives the mechanical properties of possible chassis materials.

Table 1 Comparison of materials

Material	Yield strength (N/m^2)	Modulus of elasticity (N/m^2)	Elongation at yield point (%)
AISI 1018	37705530.4	2.05e+011	15
AISI 4130	460000000	2.05e+011	25.5
AISI 1020	350000000	2.05e+011	36

AISI 1020 have better properties as compared to other materials. Thus it was chosen as the chassis material.

The dimensions of the chassis were taken for the tallest man in the group, criterions like driver comfort, minimum clearance required etc. are also considered. The minimum clearance provided is 5cm. After taking the required dimensions hollow shafts were welded. DC arc welding was used for this purpose. Figure 2 shows the CAD model of the chassis.

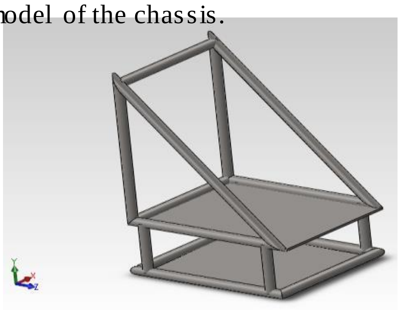

Fig. 2 Chassis

Sheet metal (thickness 3mm) was provided to avoid body contact with moving parts.

Roll Cage Material : AISI 1020 30mm hollow shaft.
Welding method : DC arc welding
Electrode : Best Arc E3147

B. WHEEL AND TIRE

The wheel and tire are the most important components of a gyrator. Unlike other vehicles wheel-tire assembly act as a crash guard for a mechanical gyrator. The assembly should be capable of withstanding the vehicle weight. The wheel is chosen in such a way that the overall centre of gravity of the system is as far as possible from the wheel centre and closer to the ground. Dimensions of the wheels are taken in such a way that the wheel should inscribe the entire chassis. A safe clearance is also provided to avoid accidents.

The material of the wheel is taken by considering the criterions like mechanical strength, cast ability, density etc. The wheel should withstand high compressive loads and the un-sprung mass should be kept minimized to ensure perfect damping of the system. Strength and cast ability should be high and the density should be low as much as possible.

The wheel may not have enough compressive strength to avoid bending, for providing this either spokes or cross members (as in the case of alloy wheels) are provided. Wheels with cross members have high impact and fatigue strength so that they can stand vibrations and shock loading better. The heat dissipation is also better. So cross members were chosen instead of spokes.

Diameter : 700mm
Material : cast alloy steel
Max width : 35 mm

The tire was chosen according to the rim offset. For providing better steer ability thin tires are used. Wide tires may impart excess friction while cornering; it may reduce the steer ability. Tire material and type were chosen according to friction coefficient. Minimum friction coefficient for treaded SBR tire of the required dimension is 0.3(for loose sand).

Type : treaded
Material : SBR
Tire pressure : 4 bar
Tire max width : 35 mm

The assembly was simple except centering. Centering gauges were not available in the lab. So according to the requirement we developed centering gauges. The centering gauge was made of hollow aluminium bar.

The centers of the wheels are obtained using the centering gauge as shown in figure 3.4 and the two cross members were welded together to form the rim. And the tires and tubes were assembled according to the design.

C. TRANSMISSION SYSTEM

The vehicle is electrically driven. Two DC geared motors are the prime movers. Geared motor provides high torque as compared to other DC motors which is sufficient to drive the mechanical gyrator. Along with gear motor, a reduction gear is also used to improve the torque. The motor gives an output of 1200rpm, the integrated gear box reduces the speed to 40rpm and finally the output from the reduction gear was 13.33rpm.

The motor used was geared DC motor of the following specification 24V 14A. Two geared motor are capable of driving the gyrator. Integrated gear box provides a reduction ratio of 30. The output of the motor was not capable for driving gyrator; the integrated gear box increases the torque by reducing the rpm. For further increase of the torque the reduction gears were provided. And it provides a reduction ratio of 2.91. The material of the gear was AISI 4130 annealed at 1138K the material has high hardness and wear resistant properties.

D. SEAT

An adjustable seat mechanism was used and it consists of 4 DC geared motors (24V, 4A 30 rpm). It enables the user to enter the vehicle from the ground level. The seat can be adjusted to any position in a 120^{o} from conventional seating position by controlling the four motors. The seat consists of 3 parts as shown in figure; upper, middle and lower parts each part can be adjusted by driving the motor. Thus the seat can be converted into a bed.

Fig. 3 Seat

E. ELECRICAL SYSTEM

The electrical system consists of Battery, Two way switches &Wiring system.

Two 24V, 14Ah battery powers the entire system. The figure 3.1 shows the circuit diagram of the electrical system used, to control the motor. A set of two, 2 way switches were used to control the motors. Stand by use: 13.6-13.8V, Cycle use: 14.1-14.4V, Maximum initial current: 1.4A

F. FINAL MODEL

Bas ed on the calculations , the final model was arrived at and was des igned in CAD. There were one main change during the development of CAD model and then later during the working. Thes e changes were incorporated for the proper working of the prototype.

G. Preliminary Model

After finding out the difficulties , the model was iterated many times. The first sketch created is shown in figure 4.

Load trans fer res ulting from acceleration or braking caus e exces s ive os cillation for the chas s is. This model has a delta s us pens ion s ys tem to damp the os cillation of the chassis.

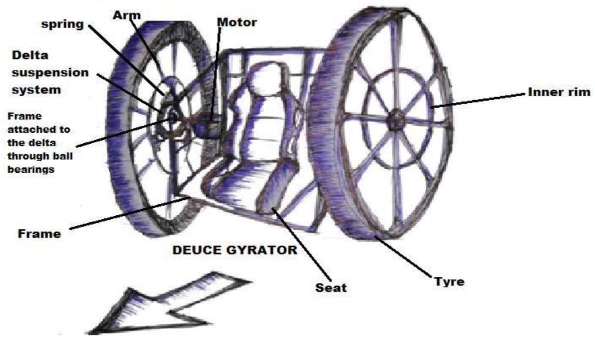

Fig. 4 Mechanical gyrator concept drawing

The major dis advantage of this s ys tem was , the chas s is cons is ts of a lot of redundant members . Thes e members increas e weight of the system there by reducing the s tability. The s eating pos ition was awkward which affects ergonomics . The wheels were wide, and it imparts large friction while cornering and the s teer ability may be affected. The motor was ins ide the cabin which cons umes large volume of boot s pace, it als o reduces the s afety of driver. That CAD model of the mechanical gyrator is shown in figure 5

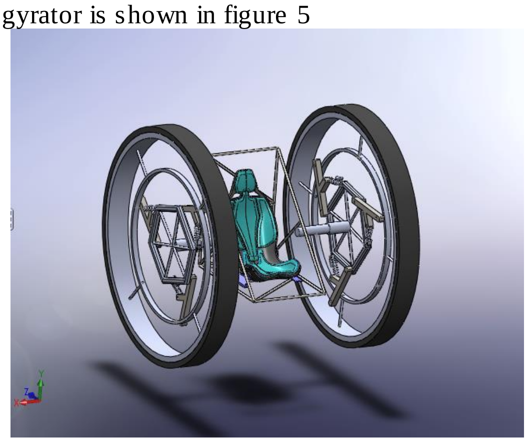

Fig. 5 Mechanical gyrator concept

CAD H. Final Model

Incorporating changes suggested from the first model, a second alternative was prepared as shown below. Thes e des igns have two major differences . Firs tly the chas sis was modified s o that it cons umes less s pace. The s hape of the chas s is was trans formed to triangular pris m. The vehicle s ize was reduced s o that the tires just ins cribe the chassis. By making the des ign s imple the total weight of the vehicle was reduced. The performance of the final des ign was bes t as compared to all the earlier models . The final CAD model is s hown in figure 6.

A separate cabin is provided for keeping the auxiliary equipment, like battery. The s liding roof made of fibre gives more comfort for the driver, it als o protects the driver from the moving parts.

The final design was then optimised by software analysis. This was explained in the next chapter.

Fig. 6 Final CAD model

III.ANALYSIS

In order optimis e the des ign s tructural analys is was done. Material s election and optimis ation of different dimens ions were done by s tructural analys is of the des ign. For modelling and analys is Solidworks 2011 was used.

Individual analysis of each component was done to minimis e the probability of failure. For s tatic analysis first components were modelled in Solidworks 2011. And the forces acting in each member was calculated. The weight of the vehicle was calculated from Solidworks its elf. Actual weight of the vehicle was approximately equal to the weight calculated us ing Solidworks . The weight of the vehicle was found to be 250kg.

A. Gear

The external gear drives the wheels. Thes e gears are welded to each wheels .s o the load acting on each wheel can be taken as the half of the total weight of the vehicle, which was 125kg. A factor of s afety of 2 was taken for accounting the unexpect ed loads . One s ide of the gear is fixed and radial load was applied on the gear which was trans mitted by the s haft. The radial load applied was 5000N, which was assumed to be distributed on the entire gear hole.

Stress, displacement, strain and displacement diagrams were plotted and the point of maximum stress was obtained.. The designed gears were capable for withstanding the static loads with a factor of safety of 70 which was much greater than the expected value. Availability of the gear readily in the market made us to choose the same gear which is not suitable for mass production because of resource wastage.

The material of the gear was AISI 4130 annealed steel at 1138K.

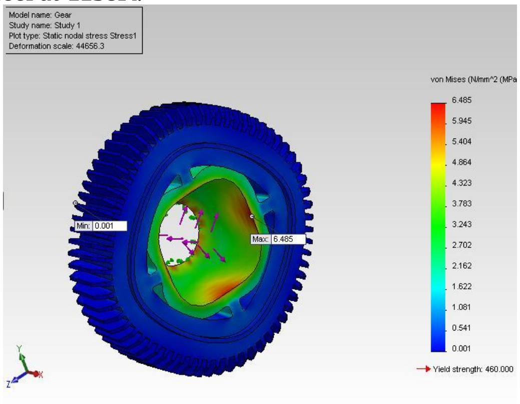

Fig. 7 Von Mises stress distribution in gear

The yield strength of the gear material was 460MPa. The maximum value of stress occurring in the gear during analysis was 6.485MPa, which was far less than the allowable value of stress.

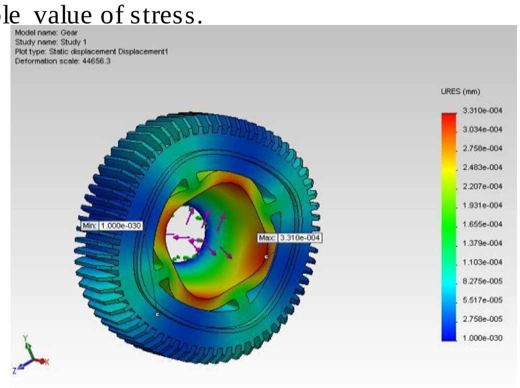

Fig. 8 Static displacement in gear

Static displacement in gear while applying a load of 5000N is shown in the figure 4.2. The maximum displacement was found to be 0.000331mm. It occurs in the inner surface of the gear. And the minimum value was found at the outer surface.

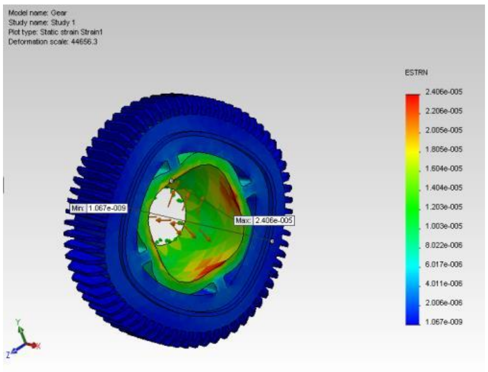

Fig. 9 Static strain in gear

Static strain in gear is shown in the figure 4.3. The maximum strain was found to be 2.4e-005. It occurs in the inner surface of the gear. And the minimum value, 1.67e-009 was found at the outer surface.

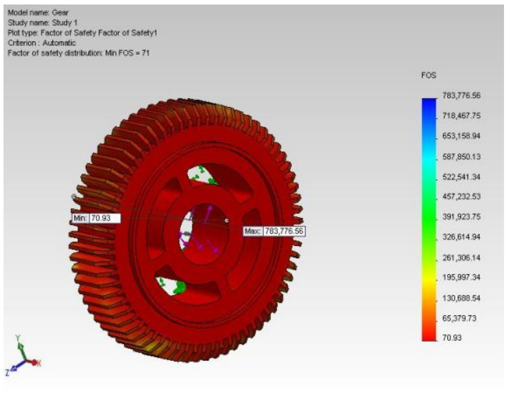

Fig. 10 Factor of safety distribution in the gear

The maximum factor of safety was 783776.56 and the minimum value was 70.93.

B. Shaft

The shaft connects the chassis with the gears through bearing. The load acting on the chassis was torsion and linear force due to static load of gyrator. It was made of cast alloy steel having high machinability. The shaft was analysed for the combination of torque and linear force. A static radial inward load of 5000N along with 15Nm torque was applied on the shaft.

The shaft was found to withstand all the load and torque acting on it. The maximum stress obtained during analysis is 81.233MPa which is much less than the yield strength of the material (248.168MPa).

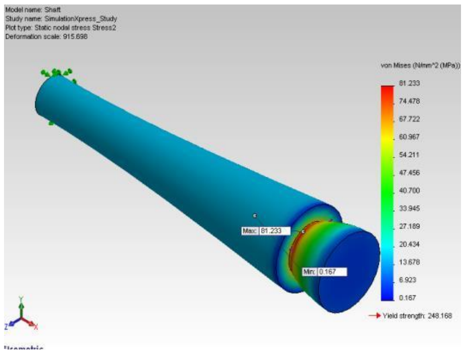

Fig. 11 Von Mises stress distribution in shaft

Von Mises stress distribution in the shaft is shown in figure 4.5. The yield strength of the shaft material was 248MPa. The maximum value of stress occurring in the shaft during analysis was 81.233MPa, which was far less than the allowable value of stress.

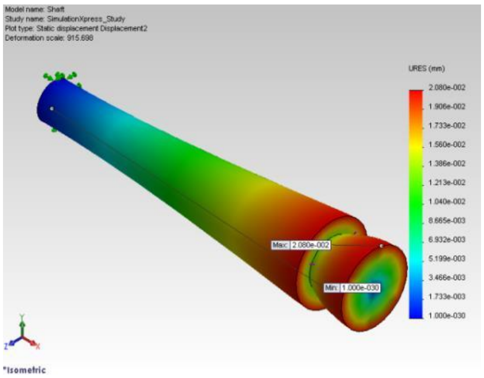

Fig. 12 Static displacement in shaft

Static displacement in shaft while applying a load of 5000N is shown in the figure 4.6. The maximum displacement was found to be 0.028mm. It occurs at the tip of the shaft. And the minimum value was found at the outer surface.

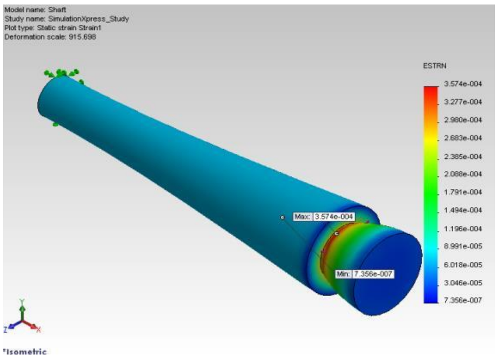

Fig.13Static strain in shaft

Static strain in shaft is shown in the figure 4.7. The maximum strain was found to be 3.57e-004. It occurs at the neck of the shaft. And the minimum value, 7.35-e007 was found at the outer surface

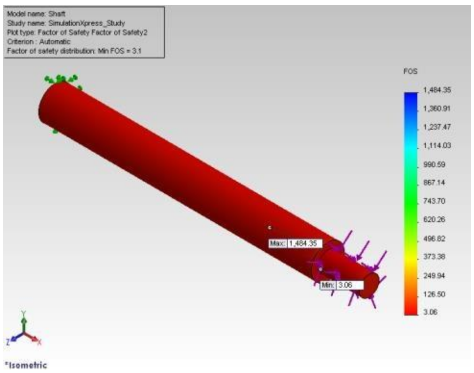

Fig. 14 Factor of safety distribution in shaft

The maximum factor of safety was found to be 1484.35 and the minimum value was 3.06.

C. Cross members

The cross members provide the bending strength for the wheels.

The material of the cross members were cast alloy steel. The material withstands all the transfers load with a minimum factor of safety of 80.45. The maximum stress obtained is 3.085Mpa which is much less than the ultimate yield strength of 248MPa.The maximum deformation was found to be 0.0001mm which was far less than the allowable deformation.

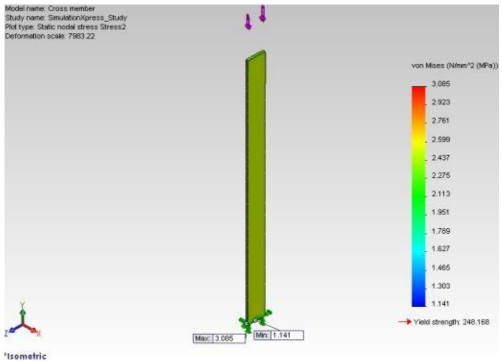

Fig. 15 Von Mises stress distribution in cross member

The yield strength of the cross member material was 248MPa. The maximum value of stress occurring in the cross member during analysis was found to be 3.085MPa, which was far less than the allowable value of stress.

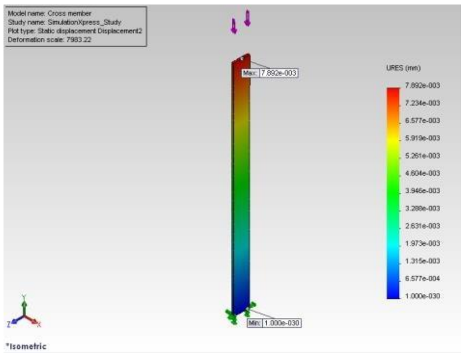

Fig. 16 Static displacement in cross member

While applying a load of 500N, the maximum dis placement was found to be 0.0078mm. It occurs at the point of application of load. And the minimum value was found at the support.

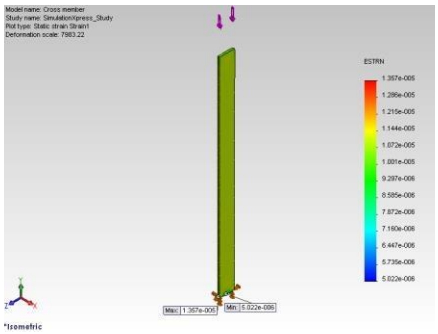

Fig. 17 Static strain in cross member

The maximum strain was found to be 1.357e-005. It occurs at the support. And the minimum value, 5.022-e006 was also found at the support.

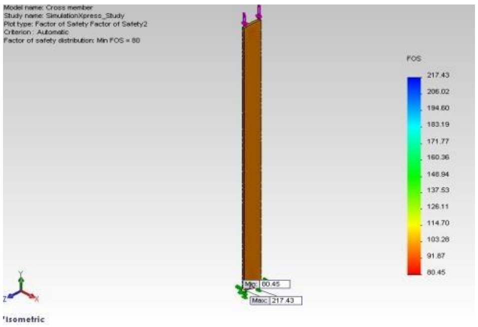

Fig. 18 Factor of safety distribution in cross member

The maximum factor of safety was found to be 217.4 and the minimum value was 80.45.

IV.WORKING OF THE PROTOYPE

The gyrator was tested by running the vehicle in different terrains. And the was design was found to be successful.
The main parameters affecting the performance follows.

Track width improves the roll stability of the vehicle. Maximum possible track width of 140cm was provided to improve the stability of the vehicle. Further increase in track width reduces manoeuvrability.
Height of the vehicle also affects the roll and pitch stability of the vehicle. The maximum height that can be provided is limited. The height of 140cm was chosen such that the vehicle just accommodates the drives with a safe clearance.
The design is done in such a way that the lateral position of the centre gravity is at a distance of 70cm from the front. The vertical distance from the ground to the centre of gravity was 40cm. the centre of gravity was kept low as possible to improve the roll stability.
A ground clearance of 150mm was provided to avoid the obstacles. Further increase in the ride height may lead to increase in the height of centre of gravity which reduces the overall stability of the vehicle.
The maximum torque and speed depend on the motor and transmission system used the given gear motor combination can provide a torque of 64.19Nm. The torque was increased to 186.8Nm by providing a proper reduction gear having gear ratio of 2.91.

V. CONCLUSION

A self-stabilizing vehicle with two wheels was designed and fabricated. The structural analysis of the design was done using Solidworks. The static displacement, Von Mises stress distribution, static strain and factor of safety distribution of various components were obtained. All the values were found to be within the safety limit. It was found that the design was intact in all the possible loading conditions.
The dynamic stability of the vehicle was achieved by lowering the centre of gravity and adjusting the lateral position. Narrow wheels were adopted to reduce the frictional resistance and the energy consumption was found to be less. Zero turning radius was achieved by rotating the wheels in opposite direction. The absence of longitudinal load transfer improves the comfort of the vehicle.

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